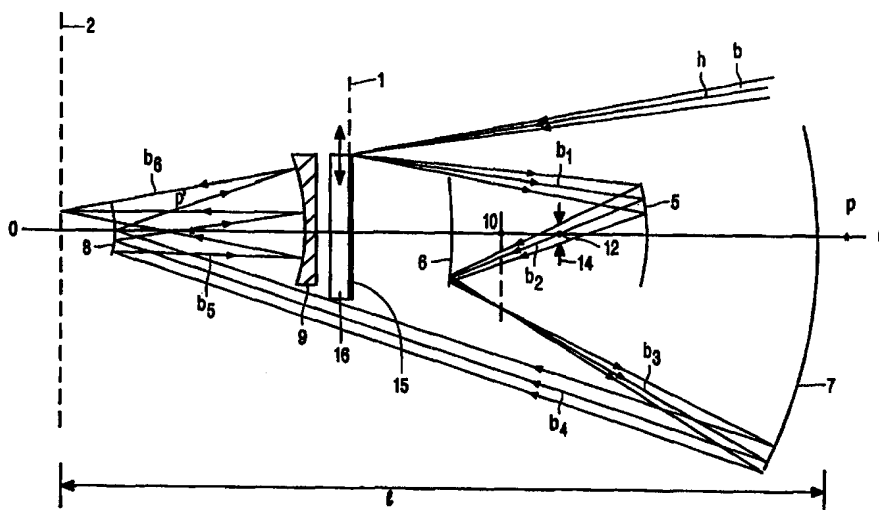




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b>  <b>G02B 17/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 99/26097</b>  <b>(43) International Publication Date:</b> 27 May 1999 (27.05.99)
<b>(21) International Application Number:</b> PCT/IB98/01639  <b>(22) International Filing Date:</b> 19 October 1998 (19.10.98)  <b>(30) Priority Data:</b> 97203536.4           13 November 1997 (13.11.97)   EP 98201055.5           2 April 1998 (02.04.98)       EP  <b>(71) Applicant:</b> KONINKLIJKE PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).  <b>(71) Applicant (for SE only):</b> PHILIPS AB [SE/SE]; Kottbygatan 7, Kista, S-164 85 Stockholm (SE).  <b>(72) Inventor:</b> BRAAT, Josephus, Johannes, Maria; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).  <b>(74) Agent:</b> COBBEN, Louis, M., H.; Internationaal Octrooibureau B.V., P.O. Box 220, NL-5600 AE Eindhoven (NL).		<b>(81) Designated States:</b> JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>

**(54) Title:** MIRROR PROJECTION SYSTEM FOR A SCANNING LITHOGRAPHIC PROJECTION APPARATUS, AND LITHOGRAPHIC APPARATUS COMPRISING SUCH A SYSTEM

**(57) Abstract**

A mirror projection system for use in a step-and-scan lithographic projection apparatus in which a mask pattern (15) is repetitively scan-imaged on a number of areas of a substrate (20) by means of a beam (b) of EUV radiation having a circular segment-shaped cross section. This system, which is easier to manufacture at lower cost than a projection system with six or more imaging mirrors, has only five imaging mirrors (5-9) with a good numerical aperture and an acceptable image-ringfield width. An EUV lithographic projection apparatus provided with the new projection system has a wafer throughput which is approximately 50 % higher than that of an apparatus provided with a six-mirror projection system. Moreover, it has a compact construction.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav	TM	Turkmenistan
BF	Burkina Faso	GR	Greece		Republic of Macedonia	TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's	NZ	New Zealand		
CM	Cameroon		Republic of Korea	PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Mirror projection system for a scanning lithographic projection apparatus, and lithographic apparatus comprising such a system.

The invention relates to a mirror projection system for use in a step-and-scan lithographic projection apparatus for imaging a mask pattern, present in a mask, on a substrate by means of a beam of EUV radiation, which beam has a circular segment-shaped cross-section.

5               The invention also relates to a lithographic apparatus for step-and-scan imaging of a mask pattern on a number of areas of a substrate, which apparatus comprises such a mirror projection system.

EP 0 779 528 A2 describes a mirror projection system for use in a step-and-scan lithographic apparatus with which an IC mask pattern is imaged on a number of  
10 areas of a semiconductor substrate, using EUV radiation. EUV, extreme ultraviolet, radiation is understood to mean radiation having a wavelength in the range between several nm and several tens of nm. This radiation is also referred to as soft X-ray radiation. The use of EUV radiation provides the great advantage that extremely small details, of the order of 0.1  $\mu\text{m}$  or less, can be imaged satisfactorily. In other words, an imaging system in which EUV  
15 radiation is used has a very high resolving power without the NA of the system having to be extremely large, so that also the depth of focus of the system still has a reasonably large value. Since no suitable material of which lenses can be made is available for EUV radiation, a mirror projection system must be used for imaging the mask pattern on the substrate, instead of a hitherto conventional lens projection system.

20               The lithographic apparatuses currently used in the production of ICs are stepping apparatuses. In these apparatuses, a full field illumination is used, i.e. all areas of the mask pattern are illuminated simultaneously and these areas are simultaneously imaged on an IC area of the substrate. After a first IC area has been illuminated, a step is made to a subsequent IC area, i.e. the substrate holder is moved in such a way that the next IC area  
25 will be positioned under the mask pattern, whereafter this area is illuminated, and so forth until all IC areas of the substrate of the mask pattern are illuminated. As is known, it remains desirable to have ICs with an increasing number of components.

It is attempted to meet this desire not only by reducing the dimensions of these components but also by enlarging the surface areas of the ICs. This means that the,

already relatively high, NA of the projection lens system must be further increased and, for a stepping apparatus, the image field of this system must also be further increased. This is practically impossible.

It has therefore been proposed to change from a stepping apparatus to a  
5 step-and-scan apparatus. In such an apparatus, a circular segment-shaped sub-area of the mask pattern and hence also such a sub-area of an IC area of the substrate is illuminated, and the mask pattern and the substrate are moved synchronously through the illumination beam, taking the magnification of the projection system into account. A subsequent circular  
10 segment-shaped sub-area of the mask pattern is then imaged each time on a corresponding sub-area of the relevant IC area on the substrate. After the entire mask pattern has been imaged on an IC area in this way, the substrate holder performs a stepping movement, i.e. the beginning of a subsequent IC area is introduced into the projection beam and the mask is set to its initial position, whereafter said subsequent IC area is scan-illuminated via the mask pattern. This scan-imaging method may be used to great advantage in a lithographic  
15 apparatus in which EUV radiation is used as projection radiation.

The embodiment of the projection system described in EP 0 779 528, intended for use with EUV radiation having a wavelength of 13 nm has an NA of 0.25 at the image side. The annular image field has an inner radius of 29 mm and an outer radius of 31 mm and a length of 30 mm. The resolution of the system is 30 nm and the aberrations and  
20 distortions are sufficiently small to form a good image of a transmission mask pattern on an IC area of a substrate by way of a scanning process. This projection system comprises six imaging mirrors, and an intermediate image is formed between the third and the fourth mirror. The mask is situated at one geometric end of the projection system, and the substrate is situated at the other geometric end of this system.

25 When such a mirror system is used in a lithographic projection apparatus, the small quantity of radiation incident on the substrate presents a problem. This problem is caused by the fact that the mirrors are considerably less than 100% reflective. Each of these mirrors comprises a multilayer structure whose composition is optimized for the relevant wavelength. Examples of such multilayer structures are described in US-A 5,153,898. With  
30 such multilayer structures, maximum reflections can be achieved which are theoretically of the order of 75% but, in practice are currently not larger than 65%. When six mirrors are used, each with a reflection of 68% in a projection system, only 9.9% of the radiation originating from the mask pattern and entering the system reaches the substrate. For a lithographic apparatus, this means in practice that the illumination time should be relatively

long so as to obtain the desired quantity of radiation energy on an IC area of the substrate, and the scanning rate should be relatively small for a scanning apparatus. However, it is essential for these apparatuses that the scanning rate is as high as possible and the illumination time is as low as possible, so that the throughput, i.e. the number of substrates  
5 which can be illuminated per unit of time, is as high as possible.

It is an object of the present invention to provide a projection system of the type described in the opening paragraph with which this requirement can be met. To this end, the projection system is characterized in that it comprises five imaging mirrors.

10 An imaging mirror is understood to be a concave (positive) mirror or a convex (negative) mirror which has a converging or a diverging effect and consequently contributes to the imaging by the mirror projection system.

Since only five imaging mirrors are used, the projection system can be manufactured more easily and at lower cost. Indeed, very stringent requirements of accuracy  
15 are imposed on an imaging mirror, so that this mirror itself is difficult to manufacture and is expensive. If such a mirror can be omitted from an optical system, this will involve a considerable reduction of cost, also because it will then be easier to assemble this system. A very important advantage of a projection system with five, instead of six, mirrors is that, in principle, the quantity of radiation on the substrate can be raised by approximately 50%. In  
20 the given example of 68% reflecting multilayer structures, the quantity of radiation incident on the substrate in a five-mirror system is 14.5% of the radiation entering the projection system. The invention is based on the recognition that, also with five imaging mirrors, a projection system can be realized having a numerical aperture which is by all means acceptable, and has sufficiently small aberrations. With the novel projection system, a  
25 circular segment-shaped scanning image spot is formed which is comparable with that formed by the known six-mirror system.

It is to be noted that US-A 5,153,898 claims a mirror projection system comprising at least three and at most five mirrors. However, it appears from the description of this patent that only three mirrors are used for the actual imaging. In the embodiment  
30 using a fourth mirror, this mirror is a flat mirror having the function of giving the imaging beam a different direction so that room is created for the substrate to perform the desired movements. An embodiment with five imaging mirrors is not described. The projection systems described in US-A 5,153,898 have a small numerical aperture, namely 0.05 or smaller, and all of them are intended for full-field illumination, hence not for use in a

scanning apparatus. It is true that US-A 5,153,898 gives the general remark that the mirror system can be made suitable for a scanning apparatus, but no design is given for a mirror system suitable for this application.

5        Within the above-mentioned design concept of the novel projection system, there is still some freedom of choice of the parameters NA, magnification and image spot. A preferred embodiment of the system is, however, characterized in that it has a numerical aperture NA of 0.20 and a magnification M of 0.25.

10        The projection system is preferably further characterized in that it consecutively comprises, from the object plane to the image plane, a concave first mirror, a convex second mirror, a concave third mirror, a convex fourth mirror and a concave fifth mirror, and the object plane is situated between the second and the fifth mirror.

      The projection system is preferably telecentric at the image side.

      Consequently, no magnification errors can occur upon undesired displacements of the substrate along the optical axis.

15        The projection system may be further characterized in that the pupil is situated between the first and the second imaging mirror.

      The system is then designed in such a way that there is sufficient space to accommodate a diaphragm at that position between the beams extending in opposite directions.

20        The projection system is preferably further characterized in that all imaging mirrors have aspherical surfaces.

      The system is then satisfactorily corrected and has a good imaging quality.

25        A mirror projection system according to the invention, which is optimal as regards radiation efficiency and build-in space, is characterized in that the object plane is situated between the second and the fifth imaging mirror and in that space for a reflective mask and its holder is reserved between these mirrors.

30        When this projection system is used in a lithographic apparatus, the dimension of the apparatus in the direction of the optical axis may remain limited because the mask holder is arranged in the projection system in which it can perform the necessary movements via the mask table accommodating the mask holder. The mirror projection system is now divided into a collimator section, consisting of the first three mirrors which jointly a substantially parallel imaging beam, and an objective section receiving this beam. The latter section, consisting of the fourth and the fifth mirror, constitutes the desired telecentric

imaging beam. An intermediate image is formed proximate to the second, convex mirror, which intermediate image is very effective for correcting curvatures of the image field. Space for accommodating a diaphragm is available between the first and the second imaging mirror.

Under circumstances, for example, when more space for the mask table is  
5 needed, it may be desirable that the mask be situated outside the projection system and at the side of this system other than where the substrate is situated, i.e. the object plane and the image plane are situated at different sides of the projection system. The concept of a projection system with five imaging mirrors can also be used in that case. The adapted embodiment of the projection system is characterized in that a plane mirror is arranged  
10 between the first and the second imaging mirror, and in that the object plane is situated outside the projection system.

The plane mirror does not contribute to the actual formation of the image, but only reverses the direction of the radiation from the first imaging mirror. Since the plane mirror can be more easily manufactured and positioned than an imaging mirror, the  
15 advantage of a projection system with five imaging mirrors, as compared with a projection system having six imaging mirrors, is maintained.

To achieve the desired optical quality, the circular segment-shaped image field of the projection system with a plane mirror has a slightly smaller width than that in a projection system with five mirrors. An embodiment of the projection system with a plane  
20 mirror having an enlarged image field is characterized in that the plane mirror has an aspherical correction surface.

Due to this aspherical surface, the projection system as a whole can be better corrected and, in principle, the circular segment-shaped image field may have an equally large width as the width in the projection system having five imaging mirrors.

25 The invention also relates to a lithographic apparatus for step-and-scan imaging of a mask pattern, present in a mask, on a number of areas of a substrate, which apparatus comprises an illumination unit with a source for EUV radiation, a mask holder for accommodating a mask, a substrate holder for accommodating a substrate, and a projection system. This apparatus is characterized in that the projection system is a mirror projection  
30 system as described above.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1 shows a first embodiment of the projection system according to the invention,

Fig. 2 shows diagrammatically an embodiment of a lithographic apparatus comprising such a projection system, and

5 Figs. 3 and 4 show a second and a third embodiment of the projection system.

In Fig. 1, the object plane, in which the mask to be imaged can be arranged, is denoted by the reference numeral 1, and the image plane, in which the substrate can be arranged, is denoted by the reference numeral 2. The image plane is illuminated with  
10 a beam  $b$  emitted by a radiation source (not shown) whose chief ray  $h$  is inclined towards the optical axis  $OO'$ . In the presence of a reflecting mask 15 in the object plane, the beam is reflected as beam  $b_1$  to the first mirror 5 of the system, which mirror is concave. This mirror reflects the beam as a converging beam  $b_2$  to the second mirror 6 which is convex. The mirror 6 reflects the beam as beam  $b_3$  to the third mirror 7. An intermediate image is formed  
15 at the position 10 between the mirrors 6 and 7. Mirror 7 is a concave mirror and reflects the beam as a substantially parallel beam  $b_4$  to the fourth mirror 8. This mirror is convex and reflects the beam as a diverging beam  $b_5$  to the fifth mirror 9 which is convex, and focuses the beam as beam  $b_6$  in the image plane 2. The mirrors 5, 6 and 7 jointly constitute a collimator section of the system, and the mirrors 8 and 9 constitute an objective section  
20 which forms the desired telecentric image on the substrate.

A diaphragm is arranged between the mirrors 5 and 6 and at the axial position 12. This is possible because the system has been designed in such a way that the beams  $b_1$  and  $b_2$  are sufficiently separated spatially at the position 12. As is known, such a diaphragm in an imaging system prevents scattered radiation or radiation caused by unwanted  
25 reflections from reaching the image-forming beam, whereby the contrast of the image formed in the plane 2 could be decreased.

Furthermore, all mirror surfaces of the system are preferably aspherical. An aspherical surface is understood to mean a surface whose fundamental shape is spherical but whose actual surface locally deviates from this fundamental shape so as to correct  
30 spherical aberrations of the system. The fundamental shape of an aspherical surface does not have to be spherical but may be alternatively plane. Also a mirror which, in principle, is plane may have a correcting aspherical surface.

The system is coaxial, which means that the centers of curvatures of all mirrors are located on one axis, the optical axis. From a point of view of assembly and



tolerances, this is very advantageous.

The following Table I shows the values of the relevant parameters of the embodiment of Fig. 1. These parameters are:

- the distances measured along the optical axis OO':

- 5  $d_1$ : between the object plane 1 and the mirror 5;
- $d_2$ : between the mirror 5 and the mirror 6;
- $d_3$ : between the mirror 6 and the mirror 7;
- $d_4$ : between the mirror 7 and the mirror 8;
- $d_5$ : between the mirror 8 and the mirror 9;
- 10  $d_6$ : between the mirror 9 and the image plane 2,

- the radii of curvature measured along the optical axis:

- $R_1$ : of the mirror 1;
- $R_2$ : of the mirror 2;
- $R_3$ : of the mirror 3;
- 15  $R_4$ : of the mirror 4;
- $R_5$ : of the mirror 5,

- the even terms  $a_2, a_4, a_6, a_8, a_{10}$  and  $a_{12}$  of the known series development:

$$Z = \sum_{i=1}^6 a_{2i} \cdot r^{2i}$$

20 describing the variation of an aspherical surface.

TABLE I

	$d_1 = 407,0280 \text{ mm.}$
25	$d_2 = -266.6040$
	$d_3 = 498,1310$
	$d_4 = -957,4880$
	$d_5 = 259,6670$
	$d_6 = -328.1660$
30	
	$R_1 = -358,6724 \text{ mm.}$
	$R_2 = -1034,9498$

$$R_3 = -753,9869$$

$$R_4 = -167,5311$$

$$R_5 = -337,4211$$

5

	mirror 1	mirror 2	mirror 3
$a_2$	-.13940298E-02	-.48311518E-03	-.66314155E-03
$a_4$	.69417630E-08	-.11947397E-07	-.13676264E-09
10 $a_6$	-.13069723E-12	.48162764E-11	-.23711675E-14
$a_8$	.28564892E-17	-.99830434E-15	.17707105E-19
$a_{10}$	-.10500535E-21	.10852556E-18	-.80978435E-25
$a_{12}$	.40366107E-26	-.47475418E-23	.14935619E-30

15

	mirror 4	mirror 5
$a_2$	-.29845209E-02	-.14818281E-02
$a_4$	-.30313077E-07	-.34399077E-08
20 $a_6$	-.28313384E-11	-.16079104E-13
$a_8$	-.11812935E-15	-.15057705E-18
$a_{10}$	-.17990104E-20	.49180832E-23
$a_{12}$	.66658543E-23	.18985871E-27

25

The system has a magnification  $M$  of +0.25, a numerical aperture  $NA$  of 0.20 and the circular segment of the image at the area of the image plane 2 has an inner radius of 24.5 mm, and an outer radius of 26 mm, so that this plane is scanned with a circular segment-shaped spot having a width of 1.5 mm. The length, or cord, of this spot is of the order of 20-25 mm. The total length of the system, 1 in Fig. 1, is approximately 1015  
 30 mm. The system is intended for forming an image by means of radiation having a wavelength of 13 nm, and to this end, the mirrors are provided in known manner with a multilayer structure which reflects radiation of this wavelength as satisfactorily as possible. Examples of multilayer structures for this purpose are described in, inter alia, US-A 5,153,898.

Fig. 2 shows very diagrammatically an embodiment of a step-and-scan lithographic apparatus which comprises a mirror system according to the invention for imaging a mask pattern, present in a reflective mask 15, on a substrate 20 which is provided with a layer 21 sensitive to EUV radiation. The apparatus comprises an illumination unit 30 which is shown diagrammatically, accommodating an EUV radiation source and an optical system for forming an illumination beam  $b$  whose cross-section has the shape of a circular segment. The mask 15 to be imaged is arranged on a mask holder 16 which forms part of a mask table 17, with which the mask can be moved in the scanning direction 18, and possibly in a direction perpendicular to the scanning direction, such that all areas of the mask pattern can be positioned under the illumination spot formed by the illumination beam  $b$ . The substrate 20 is arranged on a substrate holder 22 which is supported by a substrate table (stage) 23. This table can move the substrate in the scanning direction (X direction) but also in the Y direction perpendicular thereto. The table is supported by the support 24.

Moreover, the substrate can be moved in the Z direction, the direction of the optical axis  $OO'$ , and rotated about the Z axis. In sophisticated apparatuses, the substrate can also be tilted about the X axis and the Y axis. For further details of a step-and-scan apparatus, reference is made by way of example to PCT patent application WO 97/33204 (PHQ 96.004).

Since the mask used in combination with the projection system of Fig. 1 is a reflective mask, this mask can be fully supported. Consequently, under the influence of gravitation, this mask can remain flat on its support, which was already also the case for the substrate. This is of great importance in EUV lithographic projection apparatuses.

The projection system is telecentric on the side of the substrate, which has the advantage that no magnification errors occur upon possible unwanted movements in the Z direction of the substrate with respect to the system.

As is shown in Figs. 1 and 2, there is sufficient space between the second mirror 6 and the fifth mirror 9 to arrange the mask table, and the mask holder with the mask can be moved in that space so as to realize the desired scanning movement. Consequently, the apparatus can be given a compact design.

Moreover, the free working distance  $c$  between the fourth lens 8 and the plane of the substrate, or object plane, is sufficiently large to arrange optical sensors in the space in between. Such sensors, which are already used in stepping apparatuses or step-and-scan apparatuses in which a lens system is used as a projection system, are, for example a height and level sensor described in, for example US-A 5,191,200 (PHQ 91.007), and an

image sensor described in, for example, US-A 5,144,363 (PHQ 90.003).

The projection system shown in Fig. 3 may be used in an embodiment of the lithographic projection apparatus other than that shown in Fig. 2, in which embodiment the mask and the substrate are situated at different sides of the mirror projection system and the mask is transparent. This system also comprises five imaging mirrors 45, 46, 47, 48 and 49 which are consecutively concave, convex, concave, convex and concave, similarly as the mirrors 5, 6, 7, 8 and 9 in Fig. 1. The object plane 1 is situated on the left of the projection system and the image plane is situated on its right. In the projection apparatus, in which this projection system is used, the radiation source supplying the illumination beam  $b_{10}$  is situated on the left of the object plane 1, and the mask arranged in this plane is a transparent mask.

The beam  $b_{11}$  from the mask is incident on the first imaging mirror 45. Arranged in the path of the beam  $b_{12}$  reflected by this mirror is a plane mirror 50 which reflects the imaging beam, as beam  $b_{13}$ , to the second imaging mirror 46 which is situated proximate to the first imaging mirror 45. The imaging beam is subsequently reflected to the image plane 2, consecutively as beam  $b_{14}$ , by the convex mirror 46, as beam  $b_{15}$  by the concave mirror 47, as beam  $b_{16}$  by the convex mirror 48 and as beam  $b_{17}$  by the concave mirror 49. Now, an intermediate image is formed at the position 30 proximate to the mirror 49. A diaphragm can now be arranged between the plane mirror 50 and the convex mirror 46 at the axial position 32 where the beams  $b_{12}$  and  $b_{13}$  are just sufficiently separated. This projection system is also a coaxial system, and all imaging mirrors preferably have aspherical surfaces.

Table II states the values of the relevant parameters of the projection system shown in Fig.3. These parameters are:

- the distances measured along the optical axis  $OO'$ :

- $d_{11}$ : between the object plane 1 and the mirror 45;
- $d_{12}$ : between the mirror 45 and the mirror 50;
- $d_{13}$ : between the mirror 50 and the mirror 46;
- $d_{14}$ : between the mirror 46 and the mirror 47;
- $d_{15}$ : between the mirror 47 and the mirror 48;
- $d_{16}$ : between the mirror 48 and the mirror 49, and
- $d_{17}$ : between the mirror 49 and the image plane 2;

- the radii of curvature measured along the optical axis:

- $R_{45}$ : of the mirror 45;
- $R_{46}$ : of the mirror 46;

$R_{47}$ : of the mirror 47;

$R_{48}$ : of the mirror 48;

$R_{49}$ : of the mirror 49,

$R_{50}$ : of the mirror 50, and

5 - the even aspherical terms  $a_2$ ,  $a_4$ ,  $a_6$ ,  $a_8$ , and  $a_{10}$ .

TABLE II

10	$d_{11} = 480.0000 \text{ mm.}$		
	$d_{12} = -127.0150$		
	$d_{13} = 118.1150$		
	$d_{14} = -406.7396$		
	$d_{15} = 878.0910$		
	$d_{16} = -253.0640$		
15	$d_{17} = 329.1190$		
20	$R_{45} = -548.8380 \text{ mm.}$		
	$R_{46} = 265.3601$		
	$R_{47} = 604.7415$		
	$R_{48} = 435.3368$		
	$R_{49} = 353.7575$		
	$R_{50} = \infty$		
25	mirror 45	mirror 46	mirror 47
	$a_2$	$-.85493758\text{E-}03 \quad -.18842320\text{E-}02$	$.82677996\text{E-}03$
	$a_4$	$-.77854867\text{E-}09 \quad -.53734081\text{E-}09$	$.55026455\text{E-}09$
	$a_6$	$.13776269\text{E-}15 \quad .77436681\text{E-}12$	$.72595581\text{E-}15$
	$a_8$	$-.12932293\text{E-}18 \quad -.83937188\text{E-}17$	$.14921406\text{E-}20$
	$a_{10}$	$.72450584\text{E-}23 \quad -.32498962\text{E-}19$	$.21485301\text{E-}26$
30	mirror 48	mirror 49	
	$a_2$	$.11485359\text{E-}02$	$.14133976\text{E-}02$

$a_4$	.23885607E-07	.31344991E-08
$a_6$	.40913648E-12	.14505232E-13
$a_8$	-.82075572E-17	.80206576E-19
$a_{10}$	.40082766E-20	.48066908E-24

5

This system also has a magnification  $M$  of  $+0.25$  and a numerical aperture  $NA$  of  $0.20$  at the image side. However, the circular segment-shaped image field now has an inner radius of  $28$  mm and an outer radius of  $29$  mm, hence a width of  $1$  mm. The distance between the object plane 1 and the image plane 2, 1 in Fig. 3, is approximately

10 1020 mm.

In the projection system shown in Fig. 3, also the plane mirror may be provided with an aspherical surface. Consequently, correction is possible over a larger image field. Fig. 4 shows a mirror projection system with an aspherical, plane mirror 51. This system is distinguished from that shown in Fig. 4 in that the circular segment-shaped

15 image field has an inner radius of  $27.5$  mm and an outer radius of  $29$  mm. Table III shows the values of the parameters of this projection system, using the same notation as for the projection system shown in Fig. 3.

TABLE III

20

$$d_{11} = 480.0000 \text{ mm.}$$

$$d_{12} = -130.0000$$

$$d_{13} = 120.0000$$

$$d_{14} = -410.0000$$

25

$$d_{15} = 882.9590$$

$$d_{16} = -248.8860$$

$$d_{17} = 329.1190$$

$$R_{45} = -503.9751 \text{ mm.}$$

30

$$R_{46} = 305.4602$$

$$R_{47} = 598.5052$$

$$R_{48} = 296.8178$$

$$R_{49} = 349.0694$$

$$R_{50} = 4480.6685$$

	mirror 45	mirror 46	mirror 47
$a_2$	-.99211251E-03	-.16368743E-02	.83541463E-03
$a_4$	.19622061E-08	-.12854646E-06	.48507724E-09
5 $a_6$	.22372975E-13	.30912426E-10	.15329580E-14
$a_8$	.19165010E-18	-.10396790E-13	.14921406E-20
$a_{10}$	.72450584E-23	-.32498962E-19	-.18684709E-19
	mirror 48	mirror 49	mirror 51
10 $a_2$	.16845352E-02	.14323799E-02	.11159048E-03
$a_4$	.23195186E-07	.30343413E-08	.22374106E-07
$a_6$	.78265313E-12	.16088246E-13	-.68284347E-12
$a_8$	.23739151E-15	.67375506E-20	.62784889E-16
15 $a_{10}$	.31035106E-19	.48265639E-23	-.55338799E-20

The distance between the object plane 1 and the image plane 2,  $l_2$  in Fig. 4, is approximately 1029 mm.

The EUV lithographic projection apparatus may be used in the manufacture of ICs but also, for example, liquid crystalline display panels, integrated or planar optical systems, magnetic heads and guidance and detection patterns for magnetic domain memories.

## CLAIMS:

1. A mirror projection system for use in a step-and-scan lithographic projection apparatus for imaging a mask pattern, present in a mask, on a substrate by means of a beam of EUV radiation, which beam has a circular segment-shaped cross-section, characterized in that the mirror system comprises five imaging mirrors.
- 5 2. A mirror projection system as claimed in claim 1, characterized in that the system has a numerical aperture NA of 0.20 and a magnification M of 0.25.
3. A mirror projection system as claimed in claim 1 or 2, characterized in that the system consecutively comprises, from the object plane to the image plane, a concave first mirror, a convex second mirror, a concave third mirror, a convex fourth mirror and a  
10 concave fifth mirror, and the object plane is situated between the second and the fifth mirror.
4. A mirror projection system as claimed in claim 1, 2 or 3, characterized in that the system is telecentric at the image side.
5. A mirror projection system as claimed in claim 1, 2, 3 or 4, characterized  
15 in that the pupil is situated between the first and the second imaging mirror.
6. A mirror projection system as claimed in claim 1, 2, 3, 4 or 5, characterized in that all imaging mirrors have aspherical surfaces.
7. A mirror projection system as claimed in any one of the preceding claims, characterized in that the object plane is situated between the second and the fifth imaging  
20 mirror and in that space for a reflective mask and its holder is reserved between these mirrors.
8. A mirror projection system as claimed in any one of claims 1-6, characterized in that a plane mirror is arranged between the first and the second imaging mirror, and in that the object plane is situated outside the projection system.
- 25 9. A mirror projection system as claimed in claim 8, characterized in that the plane mirror has an aspherical correction surface.
10. A lithographic apparatus for step-and-scan imaging of a mask pattern, present in a mask, on a number of areas of a substrate, which apparatus comprises an illumination unit with a source for EUV radiation, a mask holder for accommodating a mask,



a substrate holder for accommodating a substrate, and a projection system, characterized in that the projection system comprises a mirror projection system as claimed in any one of the preceding claims.

1/4

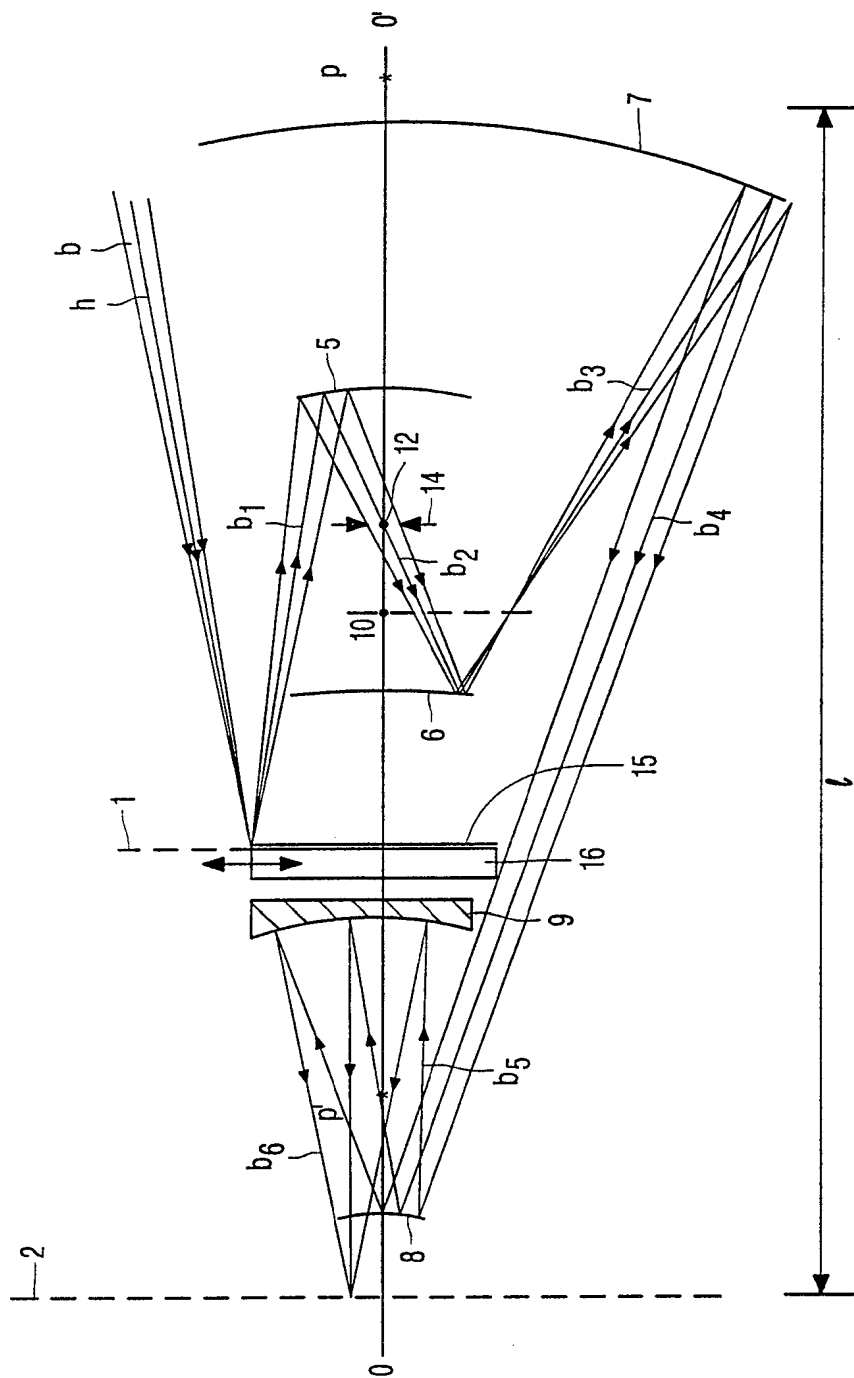


FIG. 1

2/4

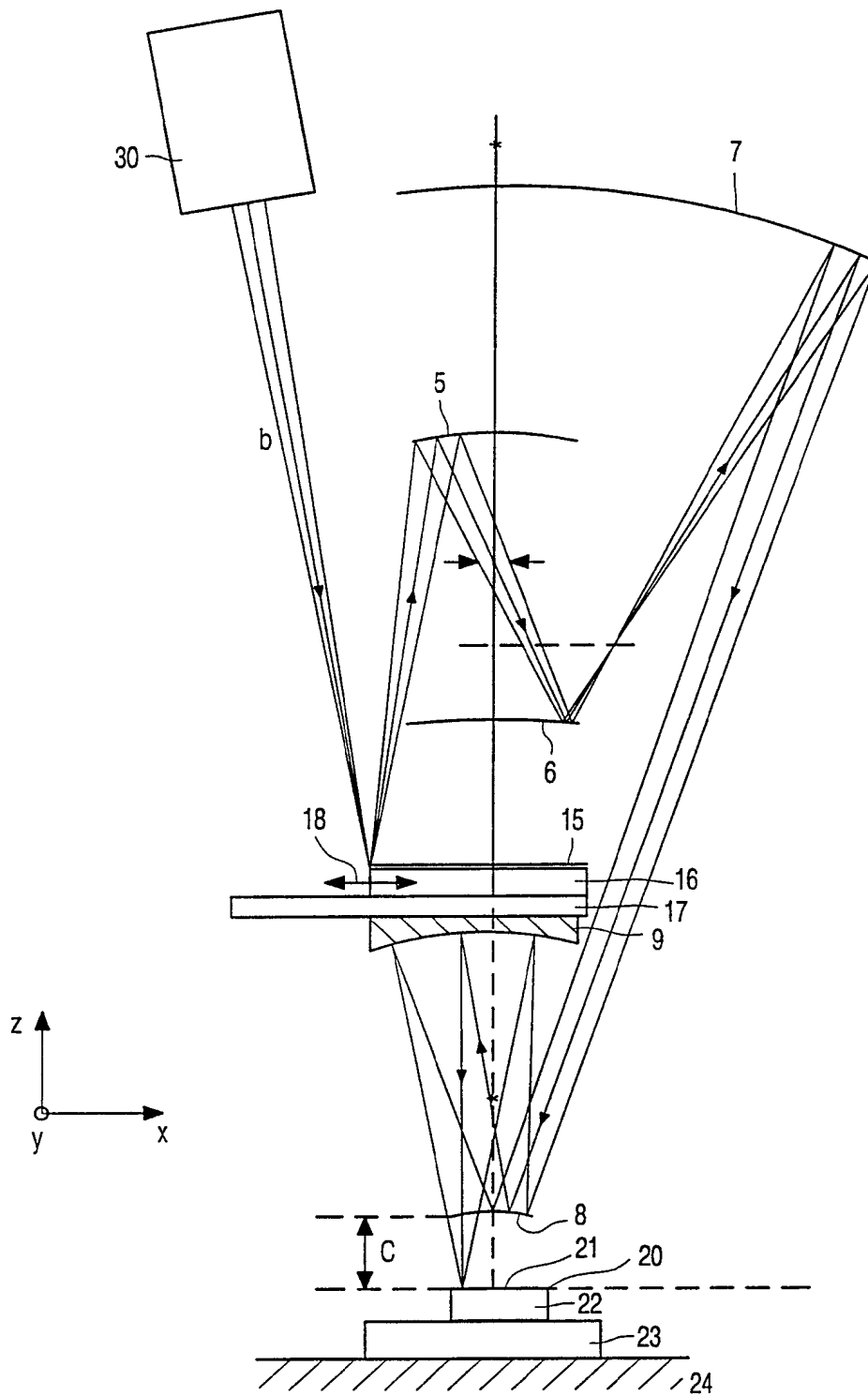
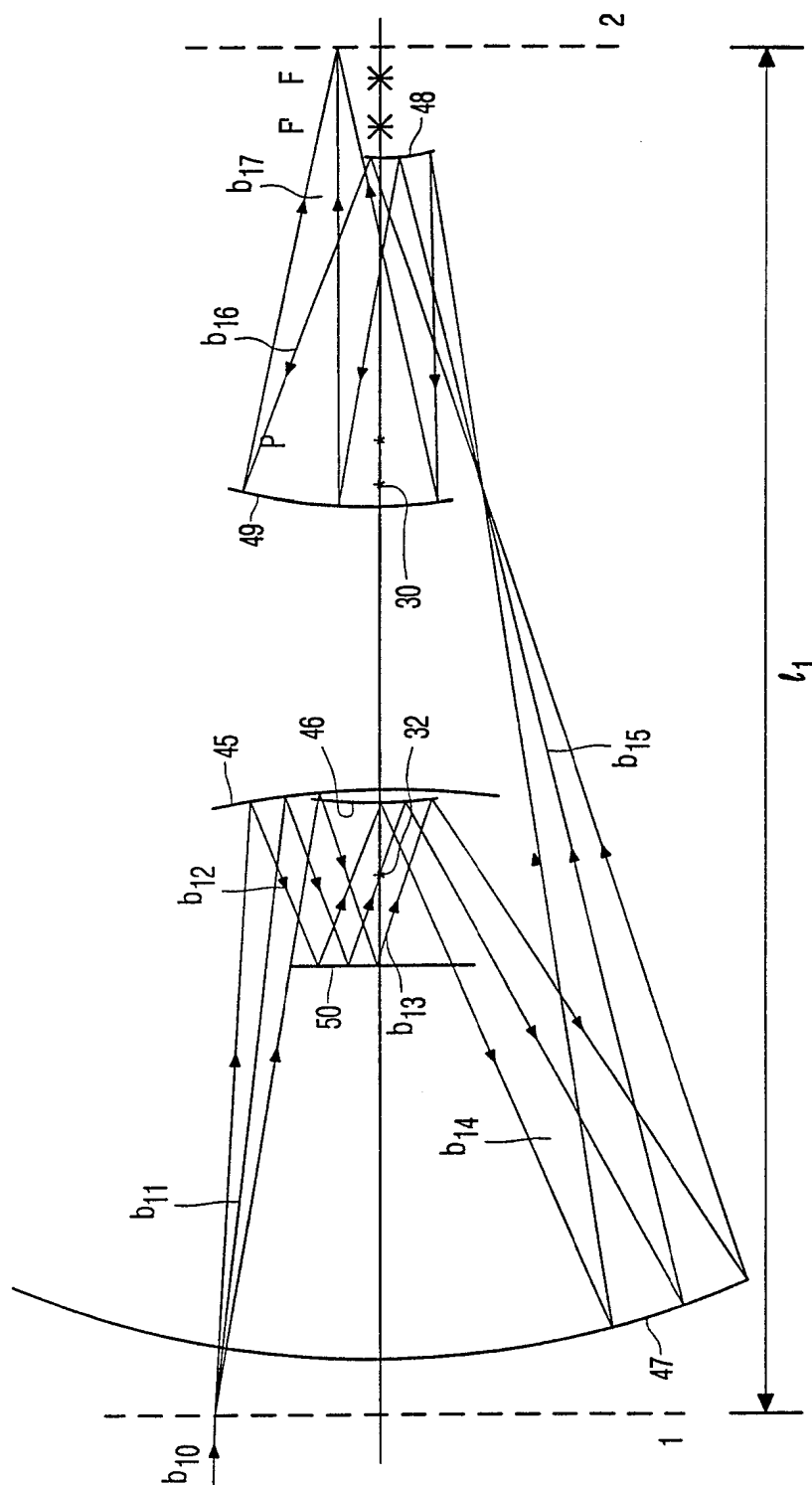


FIG. 2



**FIG. 3**

4/4

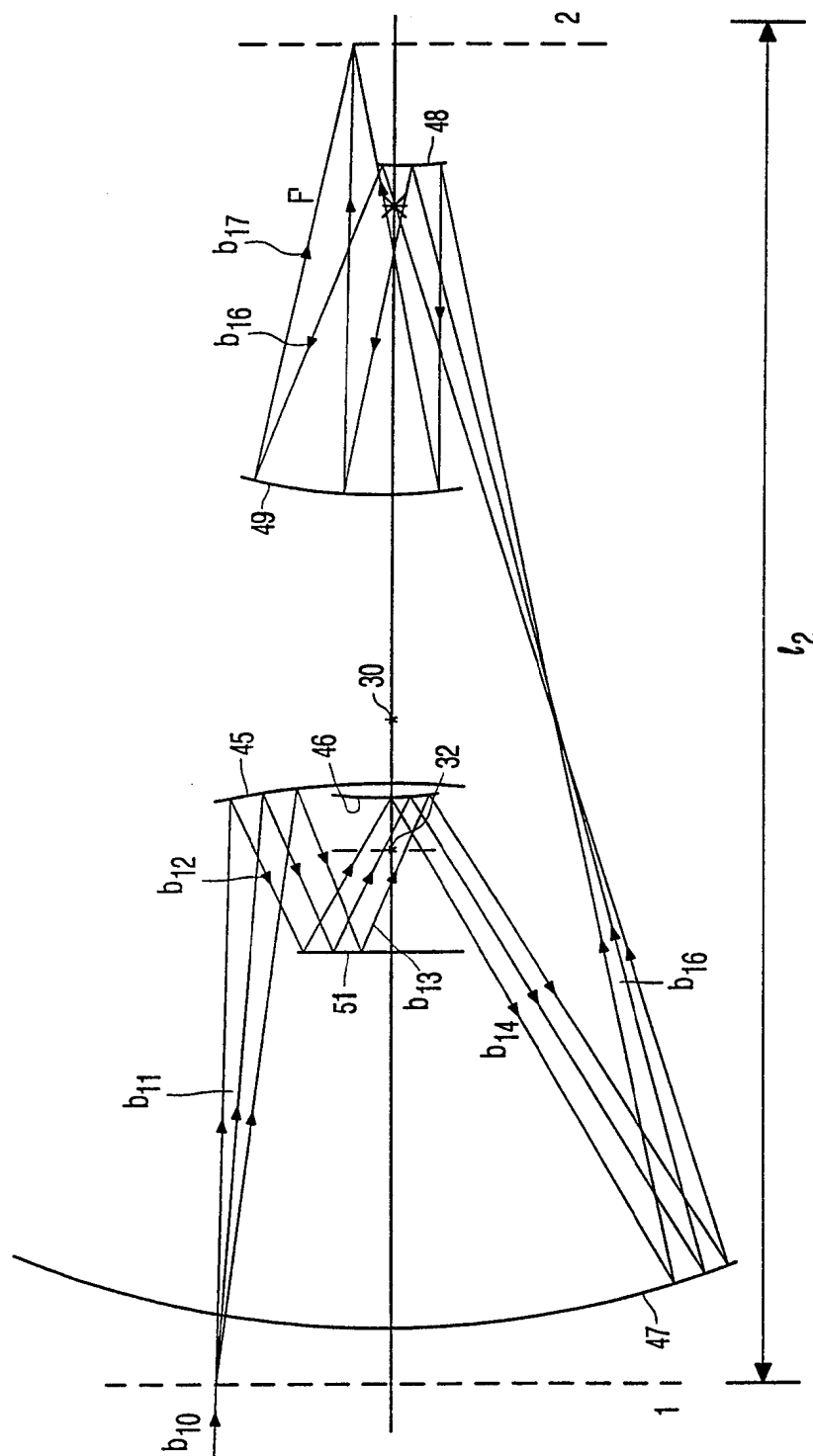


FIG. 4

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB 98/01639

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G02B 17/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G02B, G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4711535 A (SHAFER), 8 December 1987 (08.12.87), figures 1,2,4,5, claims 1-8  --	1-9
A	US 5686728 A (SHAFER), 11 November 1997 (11.11.97), figures 1,2, claims 1-14  -- -----	1-9

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

11 February 1999

Date of mailing of the international search report

16-02-1999

Name and mailing address of the ISA/  
Swedish Patent Office  
Box 5055, S-102 42 STOCKHOLM  
Facsimile No. +46 8 666 02 86

Authorized officer

Igor Gazdik  
Telephone No. +46 8 782 25 00

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

21/12/98

International application No.

**PCT/IB 98/01639**

Patent document cited in search report			Publication date	Patent family member(s)	Publication date
US	4711535	A	08/12/87	NONE	
US	5686728	A	11/11/97	JP 10090602 A	10/04/98